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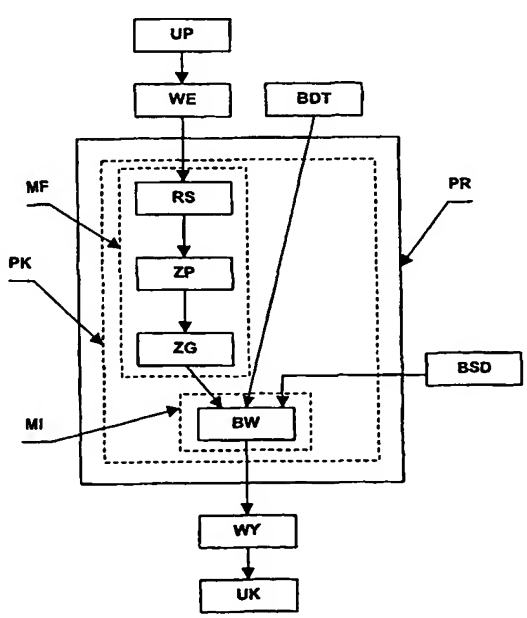
(54) Title: METHOD FOR DETECTING AND AUTOMATICALLY IDENTIFYING DEFECTS IN TECHNICAL EQUIPMENT



(57) Abstract: The subject of the invention is a method for detecting and automatically identifying defects in technical equipment, applicable in diagnosing defects in technical equipment, and especially rotational machinery. The method consists in measuring measurement signals varying in time and downloading the results of the measurements in the form of spectrograms to the memory of a computer. In the first stage peaks of amplitude values bigger than a specified amplitude threshold value are selected from spectrograms, of which peaks a set of designated peak values is created. Next, the ratio of the frequency .of each peak to the frequencies of the other peaks is calculated, whereupon, depending on the value of the obtained quotient, the set of designated peak values is divided into two subsets. In the second stage, in one of the subsets, peak groups differing from each other by the basic frequency values are distinguished. The second subset, created from the set of designated peak values, is searched for the presence of sidebands for peaks from each specified peak group and if the presence of sidebands is found, the basic frequency of the sidebands is calculated. Then, in stage three, the existence of a defect in the technical equipment is detected, which is then identified by comparing the basic frequencies and the basic frequencies of the sidebands with the frequency values collected in the memory of the computer device.

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Method for detecting and automatically identifying defects in technical equipment

The subject of the invention is a method for detecting and automatically identifying defects in technical equipment, applicable to fault diagnosing in technical equipment, especially rotating machinery.

When assessing the technical condition of technical equipment, and especially when detecting and identifying defects in rotating electric machines and their parts, methods based on the measurement of electric or mechanical signals and the spectrum analysis of these measured signals are relatively often used. Measurement signals variable in time are presented in the form of their frequency spectra, and their graphs are subjected to detailed analysis. Therefore, a spectrogram describes frequency distribution in a given signal. A peak in the spectrogram denotes the presence of a corresponding frequency in the given signal.

The standard method of defects detection and analysis consists in checking the spectrogram for peaks corresponding to the multiples of the frequency generated by the given defect. Available tools facilitate this task by visualising this process, but they do not change its principle. A disadvantage of such method of conducting the assessment of the technical condition is the necessity to exactly know the specific frequency associated with the given defect. For example, for an assessed bearing, this is the resultant of the shaft rotational frequency and the bearing geometry. If one of these data is missing, the analysis cannot be done or it is very uncertain.

From Polish patent description No. 171 505 there is known a method for assessing the technical condition of a gear transmission based on the analysis of the

vibroacoustic signal, which consists in the examination of the amplitude of spectral lines of frequencies corresponding to the product of the rotational frequency and the number of the teeth of a gear wheel, in the narrow-band spectra of the gear transmission operating at different speeds, and the frequency of the spectral line of the highest amplitude is assumed to be the local resonant frequency reflecting the stiffness of the co-operating teeth. Then, by comparing this local resonant frequency with the standard value specific for the given transmission, manufacturing faults or wear are determined.

From a Polish patent description No.148 831 there is known a method for detecting shortings and deficiencies in the stator windings of an induction motor, in which, during the motor operation, the band frequency characteristics of the motor are measured by measuring the band frequency characteristics of the tangent of the velocity or acceleration of the motor vibrations with a view to determining the occurrence in the frequency characteristics of modal values of specific frequencies characteristic of shortings and deficiencies in stator windings or their harmonics. The obtained voltage-type signal is compared with the set value, and the occurrence of a defect is signalled by exceeding this set value.

From US patent description No. 5 895 857 there is known a method of detecting defects in machinery having rotating or reciprocating elements, especially in transmissions and bearings. The method consists in selecting the amplitude peaks for specific sampling time intervals from the measured signal representing the spectra of amplitude and frequency of vibrations of the examined rotating element. These peak values are compared with the velocity signal measured by the velocity sensor that is installed on the rotating element, and the comparison of these values takes place after a previous synchronisation and averaging of the peak amplitude values and velocity signals, and these synchronously averaged amplitude values are converted to the natural frequency, in order to determine the presence of defects in the examined rotating element. The description presents also a method of converting a vibration signal generated by a vibration sensor attached to the examined rotating element to a signal representing the natural frequency generating the peak values in the spectrum.

In the presented methods of assessment of the technical condition of technical equipment measured values of various signals, shown in spectrograms, are compared with known, predetermined threshold values.

The method for detecting and automatically identifying defects in technical equipment according to the invention, in which measuring signals variable in time are measured by means of a known measuring device, and the measurement results in the form of spectrograms are fed to the memory of a computer, to which appropriate data bases are supplied, consists, at the first stage, in selecting peaks of amplitude values bigger than a specific, predetermined amplitude threshold value, out of at least one spectrogram, of which peaks a set of designated peak values is created. Then, the relation between the frequency of each peak and the frequency of the other peaks is calculated for all peaks from this set, after which, depending on the value of the obtained quotient, the set of designated peak values is divided into two subsets. Further on, in the second stage, in one of the subsets subsequent specific peak groups are distinguished, which differ from one another by the values of the basic frequency, which is one of the factors of the quotient, recurring regularly in one of those groups. For peaks from every specific peak group the presence of sidebands is sought for in the second subset created from the set of designated peak values and if the presence of sidebands is found the basic frequency of the sidebands is calculated. Next, in the third stage, the existence of a defect in the piece of technical equipment is detected and then identified by comparing the basic frequencies and the basic frequencies of the sidebands with the values of the frequencies that are stored in the computer device memory, in the data signatures base and in technical data base of the piece of the technical equipment. The results of such an analysis of the spectrogram or spectrograms are presented by means of a device for visualising the results, coupled with the computer device.

Preferably, in the first stage the set of designated peak values is divided into two subsets of peaks, where one subset comprises peak values for which the ratio of their frequency values to the frequency values of all the other peaks is expressed by the quotient of integers smaller than 10, and the second peak subset comprises all the remaining peaks.

Preferably, in the second stage, the second subset created from the set of designated peak values is searched for the presence of sidebands for any peak pairs by calculating the ratios of the difference between the frequency value of one peak of the given peak pair and the frequency value of the nearest peak from a specific peak group to the difference between the frequency value of the second peak of the given pair and the frequency value of the nearest peak from a specific peak group, after which, depending on the value of the obtained quotient, a new subset is created in the second subset, from which there are then separated subsequent peak groups differing from each other by the values of the basic frequency of the sidebands, which basic frequency is one of the factors of the quotient, consistently recurring in one of these groups.

Preferably, the new peak subset formed from peak pairs in the second subset comprises such peak pairs, for which the calculated ratios of the difference between the frequency value of one peak from the given peak pair and the frequency value of the nearest peak from a specific peak group to the difference between the frequency value of the second peak from the given pair and the frequency value of the nearest peak from the specific peak group are expressed as quotients of integers of absolute values less than 10.

The advantage of the inventive method is the possibility to detect and identify the presence of a defect in cases where the exact frequencies of the defects in specific technical equipment are not known.

The inventive method involves examining the relations between all peaks and their sidebands and searching out frequencies that are integral multiples of a certain, originally unspecified frequency. The designation of the basic frequency and the basic frequencies of the sidebands provides sufficient information to make a quantitative comparison with frequencies connected with the given defect and/or qualitative comparison with the characteristic signature of the given defect.

The subject of the invention is explained by its embodiment and a drawing where fig. 1, 2, 3, 4, show examples of spectrograms of the examined piece of equipment, wherein the consecutive steps of the realisation of the invention are indicated, and fig. 5 shows an example of equipment used to realise the method according to the invention.

The method according to the invention can be realised as follows.

1. In the spectrogram /fig.1/ supplied to the computer device, showing the value of the amplitude in the function of the frequency of the given signal of the examined technical equipment, there is indicated the threshold value of the amplitude, which is the value of the median for this diagram multiplied by 2.5. The threshold value is shown in the spectrogram in the form of a full line.

2. All the consecutive peaks of the spectrogram are compared with the threshold value of the amplitude and from peaks, for which their amplitudes are bigger than the threshold value, a set of designated peaks $A_1....A_n$, is created, where each of the peaks of this set is characterised by a different frequency value $f_1.....f_n$ /fig.2/.

3. From the set of designated peaks $A_1 ...A_n$, peaks are successively selected and for these peaks the ratio of the frequency values of these peaks divided by the frequency values of all the other peaks is calculated.

4. From peak pairs, for which calculated ratios are expressed as quotients of small integers /less than 10/ a subset {A} of the set $A_1...A_n$ is created, and from the other peaks a peak subset {Z} is created, for example, in fig. 3 these are peaks A_6, A_9, A_{15}, A_{18} from the subset {A}, for which the ratios of peak frequencies $f_{15}/f_6 = 3/1$, $f_{18}/f_9 = 2/1$, $f_{15}/f_9 = 3/2$ and f_7/f_4 from the subset {Z} of ratio = 217/100.

5. Then, from the subset {A} successive groups of peaks $B_1...B_n$, $C_1...C_n$, $D_1....D_n$ etc. are separated, which differ from each other by frequency values constituting one of the factors of the product that recurs in the given group $B_1...B_n$ or $C_1...C_n$ or $D_1....D_n$, the other factor of the product is any integer. The recurring product factor constitutes basic frequency ω_b, ω_c or ω_d of the given peak group. Peaks A_6, A_9, A_{15}, A_{18} form a set $B_1....B_4$ of basic frequency ω_b= 4.95, /fig.3/.

6. Next, for all peaks from the group $B_1 ....B_n$ the presence of sidebands is sought for. For this purpose further analysis of the spectrograms is carried out, which consists in the following:

a/ from the peak subset {Z} all peak pairs of frequencies $\{fz_j, fz_k\}$ are selected and for each peak pair there is calculated the ratio of the difference between the peak frequency value fz_j and such frequency value of a peak from the group $B_1....B_n$, which is the nearest to the peak of the value fz_j, divided by the difference between peak frequency value fz_k and such frequency value of a peak from the group $B_1....B_n$, which is the nearest to the peak of the value fz_k.

b/ from peak pairs, for which the calculated ratios are expressed as quotients of small integers /of absolute value less than 10/ a subset {ZZ} of the set {Z} is created, for example, in fig. 4, the ratio of the distance $A_4 - B_1$ to the distance $A_5 - B_1$ is 2:1, and the ratio of the distance $A_{10} - B_2$ to the distance $A_5 - B_1$ is -1:1,

c/ if in subsection b/ the subset {ZZ} is an empty set for peaks from the group $B_1 \ldots B_n$, and from the groups $C_1 \ldots C_n$, $D_1 \ldots D_n$ etc., then the absence of sidebands is found and the actions presented in section 7 are performed, if not, actions mentioned in subsection d/ are performed,

d/ Then, from the subset {ZZ} successive peak groups $b_1 \ldots b_n$, $c_1 \ldots c_n$, $d_1 \ldots d_n$ etc. are separated, which differ from each other by the values of rotational frequencies, constituting one of the factors of the product, which recurs in the given subset $b_1 \ldots b_n$ or $c_1 \ldots c_n$ or $d_1 \ldots d_n$, the other factor of the product is any integer. The recurring product factor is the basic frequency of sidebands ω_{b1}, ω_{c1} or ω_{d1} of the given peak group, for example, peaks b_1, b_2, b_3 are sidebands of peak B_1, peaks b_4, b_5 – of peak B_2, peaks b_6, b_7 – of peak B_3, and peak b_8 - of peak B_4 /fig.4/.

e/ the actions presented in subsections a-d are repeated for peak groups $C_1 \ldots C_n$, $D_1 \ldots D_n$, etc. described in item 5.

7. The separated basic frequencies ω_b, ω_c or ω_d and the basic frequencies of sidebands ω_{b1}, ω_{c1} or ω_{d1} of a given peak group are compared with the frequency values, which are collected in the data signature base BSD, as frequencies known for various types of defects, and depending on the type of the technical equipment whose technical data are collected in the technical data base BDT – the type of defect of the given technical equipment is detected and identified. Next, the result of such analysis of a spectrogram or spectrograms are presented by means of a results visualisation device coupled with a computer device.

For example, the existence of a bearing defect can be inferred from the existence of distinct peaks in the spectrum. From the fact that the basic frequency ω_b is approximately equal to 5X the rotational frequency of the piece of equipment and from the fact of existence of sidebands it can be inferred that the defect is connected with the inner race of the bearing. In the case of a defect of the outer raceway, the basic frequency would usually be lower and there would be no sidebands. Other defects can be eliminated in a similar way and the type of the defect can be determined with considerable likelihood, and a precise knowledge of frequencies connected with a bearing defect is not required while conducting the analysis.

The inventive method is realised in a device for detecting and automatically identifying defects in technical equipment.

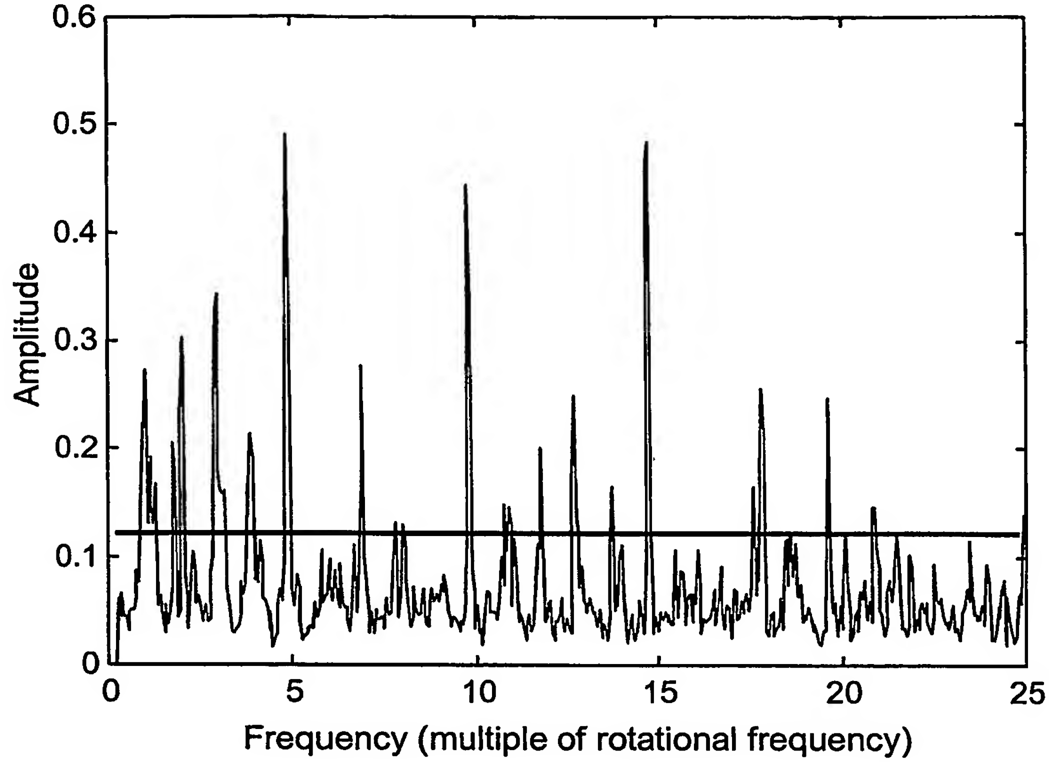
This device is a processor PR, incorporating memory PK, in which a functional module MF and an identification module MI can be distinguished. The functional module MF comprises a spectrograms register RS, a peak selection and register unit ZP and a group classification unit ZG. The functional module MF via the spectrograms register RS is connected through an input WE of the processor PR, to which input a measuring device UP is connected if any on-line measurements are made. Any information carrier containing measurement data can be connected to the spectrograms register RS through the input WE. The output of the functional module MF is connected with the identification module MI, to which the base of technical data characterising the given examined piece of equipment BDT and the defects signature database BDS are connected. The output of the identification module MI is at the same time the output WY of the processor PR and it is connected with the final report visualisation device UK, which can be a display on the computer screen or a printer.

Claims

1. A method for detecting and automatically identifying defects in technical equipment, wherein measurement signals varying with time are measured by means of a known measuring device, and the results of the measurements in the form of spectrograms are downloaded to the memory of a computer, to which appropriate data bases are also downloaded, **characterised in** that in the first stage peaks of amplitude values bigger than a specified set amplitude threshold value are selected from at least one spectrogram, of which peaks a set of designated peak values is created, then the ratio of the frequency of each peak to the frequency of the other peaks is calculated for all peaks of this set, whereupon, depending on the value of the obtained quotient, the set of designated peak values is divided into two subsets, and then in the second stage in one of the subsets successive specific peak groups are distinguished, which differ from each other by the values of the basic frequency, constituting one of the product factors, consistently recurring in one of these groups, whereupon for peaks from every specific peak group the presence of sidebands is sought for in the second subset created from the set of designated peak values and if the presence of sidebands is found, the basic frequency of the sidebands is calculated, after which, in stage three, the presence of a defect in the technical equipment is detected, which is then identified by comparing the basic frequencies and the basic frequencies of the sidebands with the frequency values collected in the computer device memory, in the data signature base and in the base containing technical data

of the technical equipment, and then the result of such analysis of the spectrogram or spectrograms is presented by means of a results visualisation device coupled with the computer device.

2. A method according to claim 1, **characterised in** that in the first stage the set of designated peak values is divided into two subsets of peaks, one subset comprising such peak values for which the ratio of their frequency values to the frequency values of all the other peaks is expressed by a quotient of integers smaller than 10, and the other peak subset consists of all the other peaks.
3. A method according to claim 1, **characterised in** that in the second stage, the second subset created from the set of designated peak values is searched for the presence of sidebands for any peak pairs, by calculating the ratios of the difference between the frequency value of one peak of the given peak pair and the frequency value of the nearest peak from a specific peak group to the difference between the frequency value of the second peak of the given pair and the frequency value of the nearest peak from a specific peak group, after which, depending on the value of the obtained quotient, a new subset is created in the second subset, from which there are then separated subsequent peak groups differing from each other by the values of the basic frequency of the sidebands, which basic frequency is one of the factors of the quotient, consistently recurring in one of these groups.
4. A method according to claim 3, **characterised in** that the new peak subset created from peak pairs in the second subset consists of such peak pairs, for which the calculated ratios of the difference between the frequency value of one peak from the given peak pair and the frequency value of the nearest peak from the specific peak group to the difference between the frequency value of the second peak from the given pair and the frequency value of the nearest peak from the specific peak group, are expressed in the form of quotients of integers of absolute value smaller than 10.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Amplitude
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15
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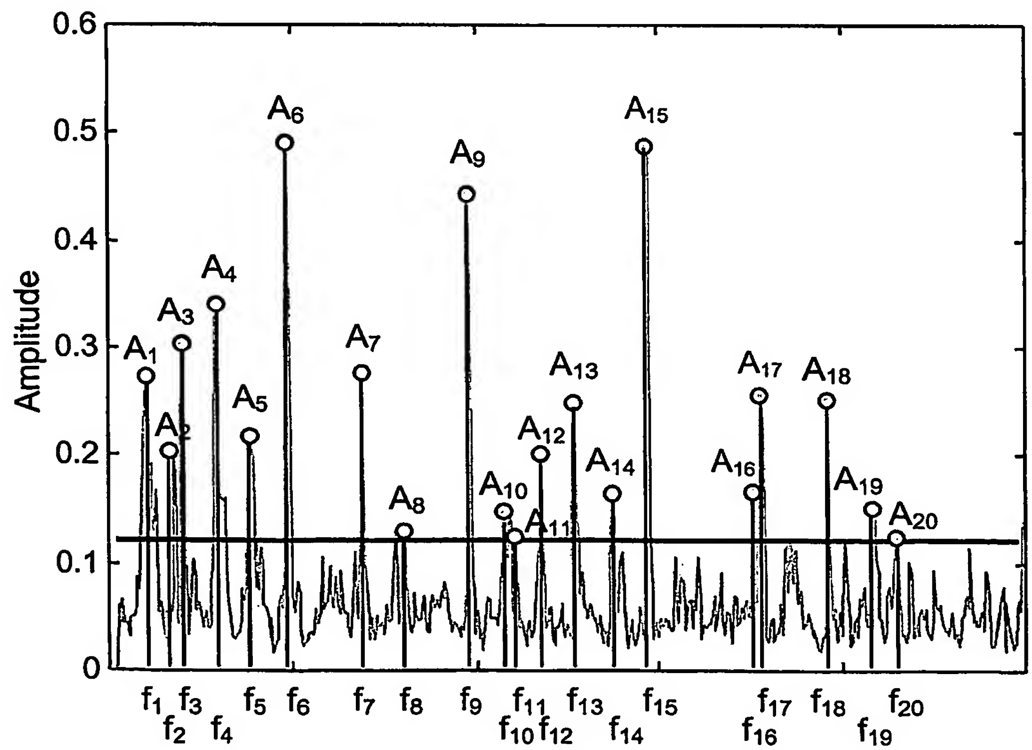
25
Frequency (multiple of rotational frequency)

Fig.1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Amplitude
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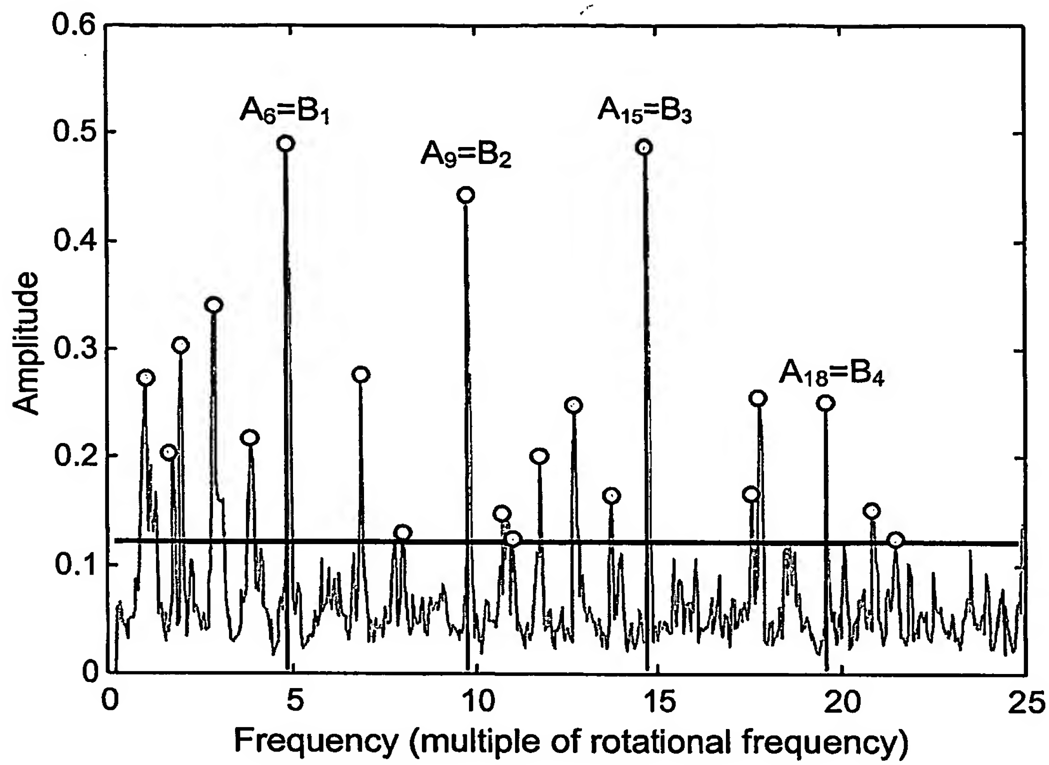
Fig.2



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0.1
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Amplitude
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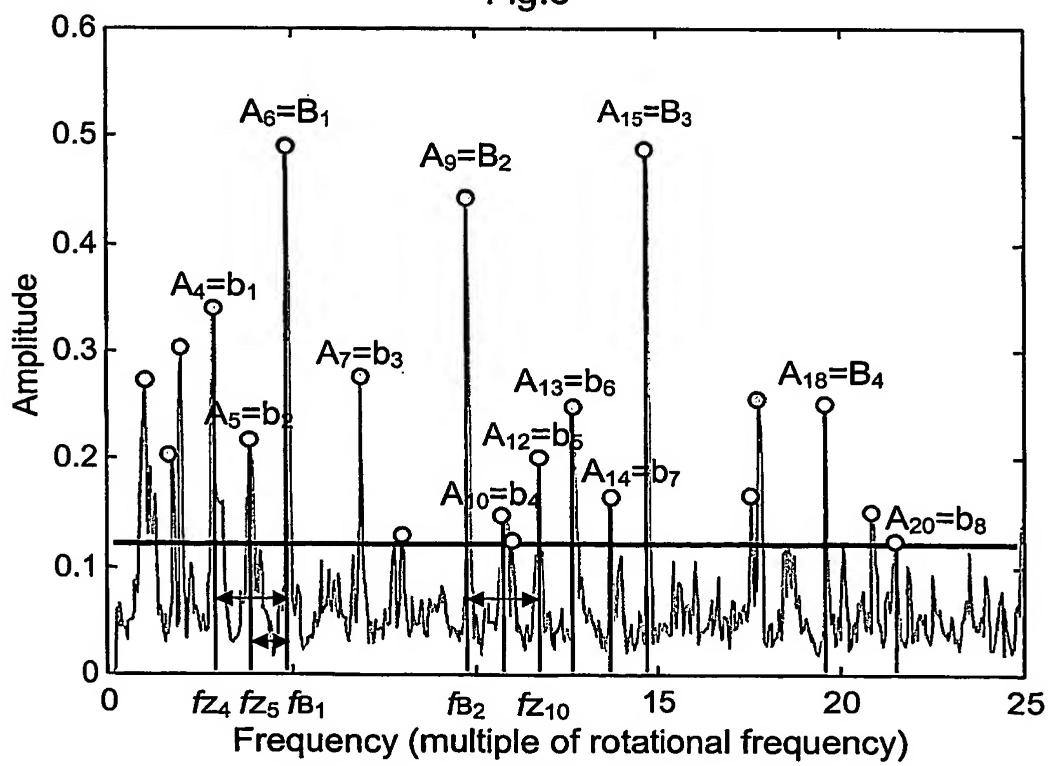
Frequency (multiple of rotational frequency)

Fig.3



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Amplitude
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A14=b7
A10=b4
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fB2
fz10
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20
25
Frequency (multiple of rotational frequency)

Fig.4

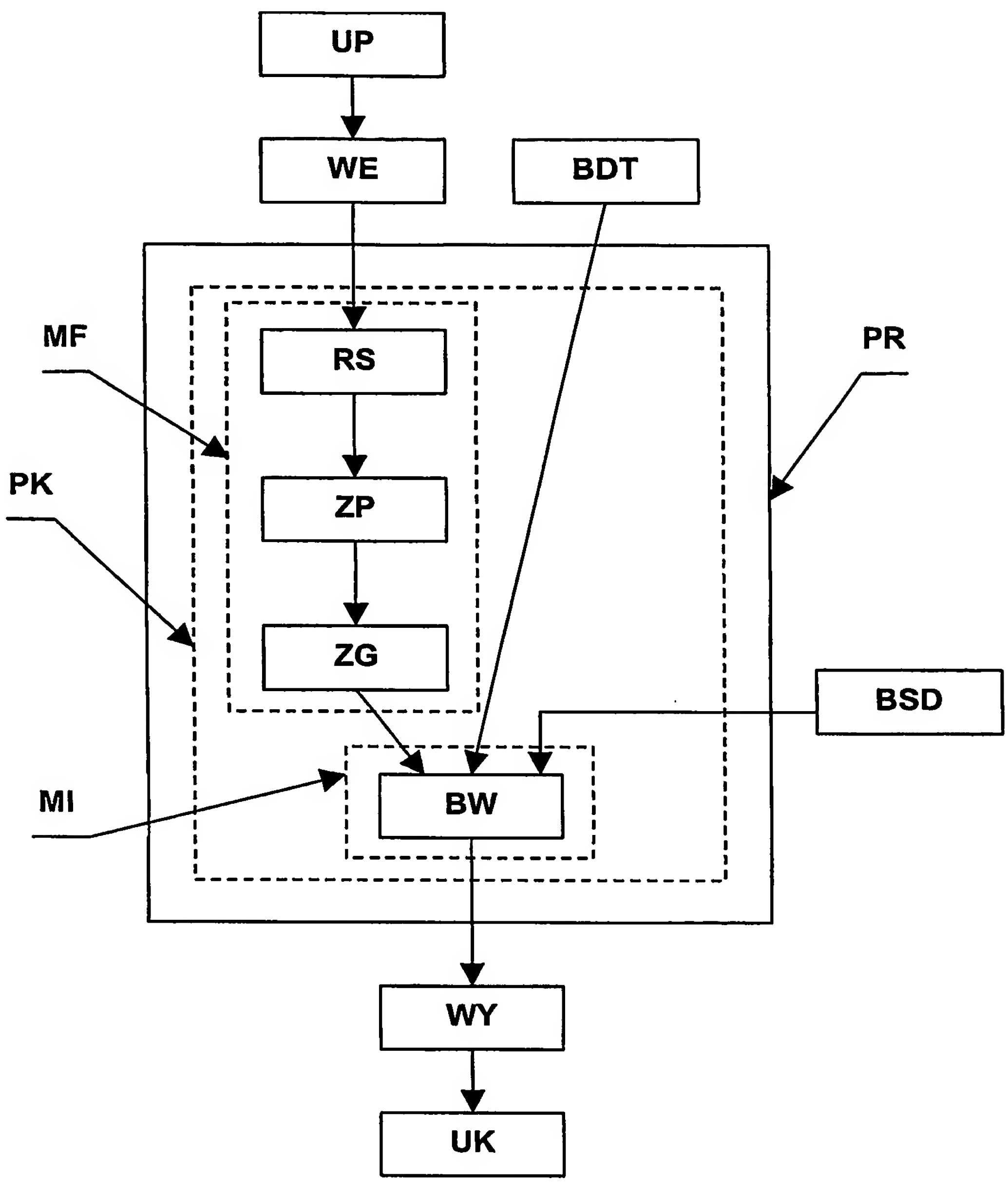

Fig. 5

INTERNATIONAL SEARCH REPORT

PCT/PL 02/00072

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01H1/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 875 420 A (BETHMANN JR WILLIAM F ET AL) 23 February 1999 (1999-02-23) column 5, line 30 - line 59 column 11, line 44 - line 67	1-4
A	US 5 483 833 A (DICKENS LARRY M ET AL) 16 January 1996 (1996-01-16) column 6, line 25 - line 62	1-4
A	US 5 686 669 A (HERNANDEZ WALTER C ET AL) 11 November 1997 (1997-11-11) column 6, line 10 - line 60	1-4

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 June 2003	25/06/2003

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Swartjes, H.

1

INTERNATIONAL SEARCH REPORT

on patent family members

PCT/PL 02/00072

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